the same as in average rocks, and is insufficient to account for one-hundredth part of the helium present.

On the other hand, a solution of the mineral gave abundant thorium emanation. I am inclined to think that there is some unknown complicatior about the thorium-emanating power of solutions, which makes it unsafe, in certain cases at least, to infer from it the quantity of thorium present. But enough thorium emanation was given off by the solution to show that thorium was a substantial constituent of the mineral. I regard it as entirely certain that the helium in this mineral has not been generated *in situ* by uranium or radium, and have no hesitation in connecting it with the presence of thorium.

On the Measurement of Temperatures in the Cylinder of a Gas Engine.

By Professor H. L. Callendar, F.R.S., and Professor W. E. Dalby, M.A., M.Inst.C.E.

(Received October 8,—Read November 7, 1907.)

1. *Introductory.*—It is important in the experimental investigation of the internal combustion engine to be able to measure directly the temperature of the working fluid at some point of the cycle. If the temperature at a suitable point of the cycle is known, the laws of gases enable us to calculate the temperature at any other point during compression and expansion from the indicator diagram on the assumption that the mass remains constant and that the molecular change occurring in combustion is known. The method usually employed has been to estimate the temperature at the beginning of compression (the temperature at this point is sometimes referred to as the "suction temperature") by computing the total mass of the cylinder contents at this point from a knowledge of the gas and air supply and an estimate of the temperature and mass of the contents of the clearance space. But this is an indirect and troublesome method, and some of the data required are extremely uncertain. Direct measurements of the temperature in the cylinder under working conditions have hitherto failed for various reasons. Professor F. W. Burstall* was the first to employ the platinum thermometer for this purpose. He used wires 0·0025 and 0·0015 inch in diameter, and obtained a good deal of valuable information from his experiments, but he

* 'Phil. Mag.,' June, 1895.

did not succeed in measuring the temperature under ordinary working conditions. In his latest report* he says:—

"All attempts to use these wires with an engine firing at every second revolution resulted in the destruction of the wire before a sufficient number of observations could be taken. The temperatures have, therefore, been measured on an engine running dead light, that is firing about one in six of the possible explosions."

These conditions are quite abnormal, and the results from these experiments cannot, therefore, throw much light on the question of the temperatures corresponding to full load conditions.†

Professor B. Hopkinson‡ has recently suggested that the suction temperature might be measured with a wire sufficiently thick to withstand the explosion temperature without melting, and has developed an ingenious method of correcting the indications of a thick wire so as to deduce the temperature of the gas in the cylinder. The method of correction, though somewhat elaborate, appears to have been satisfactory for temperatures up to 300° C., but his final conclusion is as follows:—

"The large size of the wire (namely, 0·004 inch) was chosen because it was intended ultimately to use it for measuring the suction temperature when the engine was working in the ordinary way, taking in and firing a charge of gas. But it was found that even this large wire always fused before any observations could be taken. A still thicker wire might of course have been used for the purpose, but the correction would then have been so great as to make the results valueless."

2. *Method employed by the Authors.*—In order to avoid troublesome and uncertain corrections, it is necessary that the wire employed should be fine enough to follow the changes of temperature of the gas very closely during suction and compression. To employ such a wire in the cylinder under working conditions, it is further necessary that it should be perfectly screened from the flame during explosion. Any apparatus for the introduction and withdrawal of the thermometer must be such as not to make any change in the usual form and extent of the clearance surface during the time interval comprising the end of compression. Otherwise the normal conditions of working would be changed, and a risk of pre-ignition would be introduced. The arrangement used by the authors was designed to satisfy these conditions. The thermometer was contained in a small valve (T, fig. 1), called the

* 'Proc. Inst. Mech. Eng.,' October, 1901, p. 1050.

† The mixtures used were very weak, being one of gas to 12 of air, and the correction for radiation error at the maximum temperatures is very large.

‡ 'Phil. Mag.,' January, 1907.

thermometer valve, inserted through the spindle of the admission valve A, which was bored out to receive it. The admission valve casting C is shown detached from the engine cylinder, and the thermometer valve T is shown

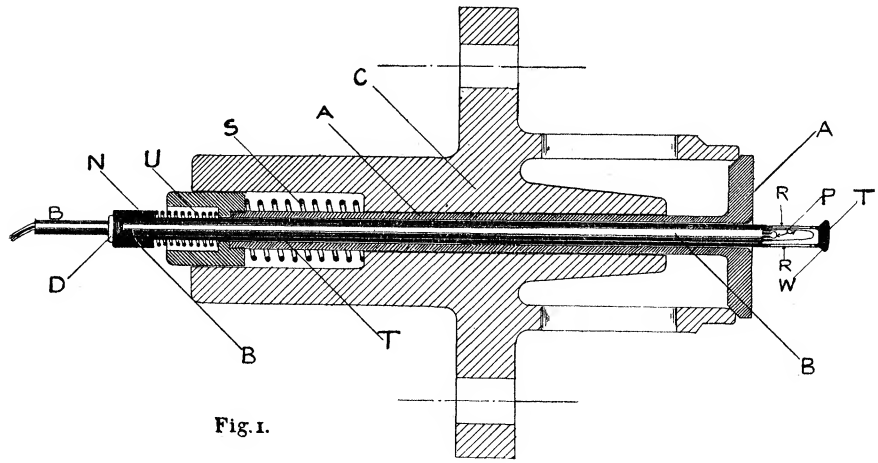

Fig. 1.

open to its fullest extent, the maximum lift being 1·5 inches. The head W of the valve T has a seating in the head of the admission valve A. The valve T is closed by a spring U, shown in compression, acting on a nut N. The thermometer leads are enclosed in a brass tube B fitting inside the spindle of the valve T. The tube can be inserted or withdrawn without dismounting the valve. It is held in place by a collar D which is screwed home against the nut N. The platinum wires forming the thermometer are seen at P. The head W of the valve T is connected to the tube forming the spindle by the two ribs R and R, which are made as thin as possible in order to leave the platinum wires freely exposed to the gas when the valve is pushed in.

Two views of the combined admission and thermometer valves are shown in figs. 2 and 3 reproduced from photographs, fig. 2 showing the thermometer valve opened to its fullest extent, fig. 3 showing it closed.

The gear for operating the thermometer valve is shown diagrammatically in fig. 4. A fixed casting F carries a shaft Q, to which is keyed a long lever L, and a short lever *l*. The short lever ends in a roller which is held up by a spring against the cam E, keyed to the lay shaft of the engine. The end of the long lever L acts on the nut N at the end of the thermometer valve T, and is forked so as to clear the brass tube B of the thermometer. The end of the lever operating the admission valve A is similarly forked to clear the thermometer valve T. Any desired timing of the exposure of the thermometer valve T in the cylinder may be obtained by adjusting the form

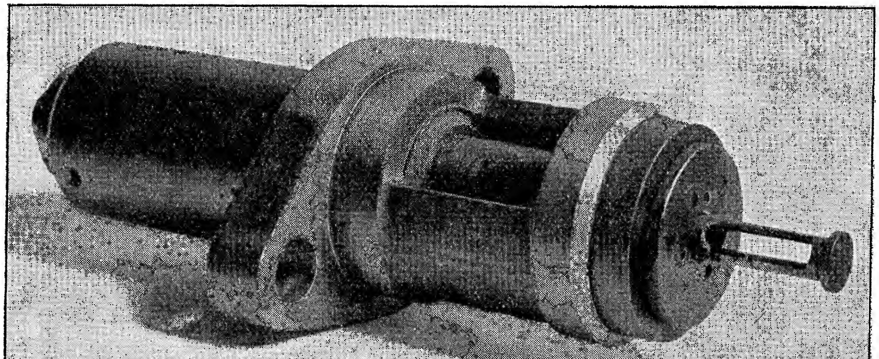

Fig. 2.

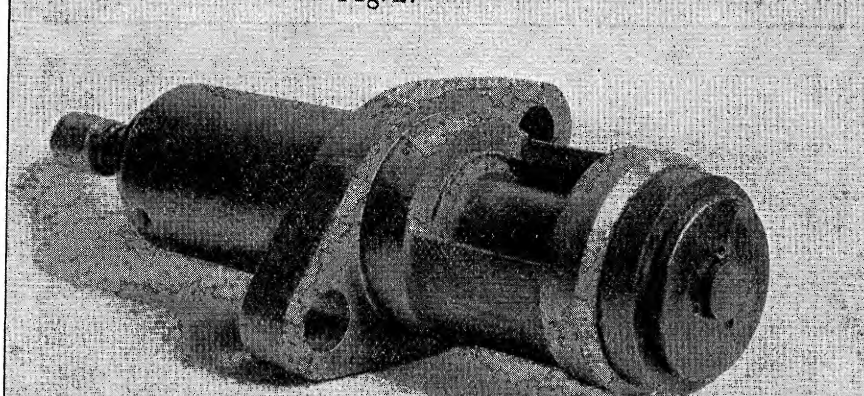

Fig. 3.

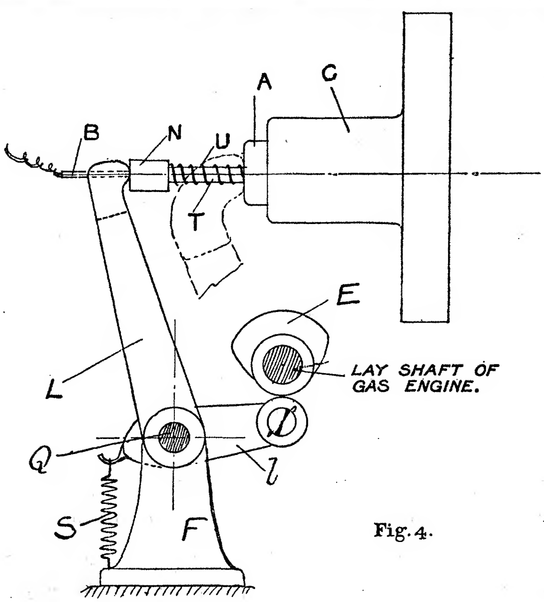

Fig. 4.

and position of the cam E. In the gas trials described below the thermometer valve was arranged to open during suction and close towards the end of compression.

3. *The Platinum Thermometers.*—The platinum thermometers and accessory apparatus for observing the temperatures were similar to those employed by Callendar and Nicholson in their experiments on the steam-engine,* but the thermometers were of somewhat simpler construction, since they were not required to be exposed to high pressures or temperatures. The leads were a pair of twin wires, insulated with rubber and cotton, and were fixed gas tight in the brass containing tube. The projecting ends of the copper leads were held in place with mica washers. A loop of platinum wire, 0·001 inch diameter and 1 inch long, was soldered to the ends of the thermometer leads. The ends of the compensator leads were similarly connected by a loop of the same wire, $\frac{3}{8}$ inch long. The thermometer and compensator were connected to opposite sides of the Wheatstone bridge, so that the bridge reading gave the difference of resistance between them, corresponding to the resistance of the middle $\frac{5}{8}$ inch of the thermometer loop. This provision of a compensating loop has often been overlooked, but is most essential when using short loops of fine wire for the measurement of rapidly varying temperatures. The ends of the fine wire loops close to the leads are affected by conduction of heat to or from the leads, and cannot follow the rapid variations of temperature; but the end effect is eliminated by observing the difference between two loops of different lengths. The lengths of the loops were chosen so as to give with the wire actually employed a change of resistance of 1 ohm approximately for 100° C. Shorter lengths might have been employed without material reduction of sensitiveness, but the above lengths were found to be sufficiently stiff to stand the commotion in the cylinder satisfactorily for long periods. After each run the thermometer was removed and placed in a tube in a vessel of water. Its resistance was then measured at the temperature of the laboratory, in order to test for variations of the zero. It was found that the zero was generally raised after a run of half an hour or so by about one-fifth of a degree C., owing to slight strain or distortion of the wire; but it was easy to take account of these small changes, which would not, if neglected, however, have materially affected the accuracy of the measurements. The current employed in measuring the resistance was about the 1/200 part of an ampere. The heating effect of this current on the thermometer was measured and found to be less than a quarter of a degree C. The same current was employed in determining the fundamental interval of the thermometers. The heating effect could be safely neglected, as it was nearly

* 'Proc. Inst. C.E.,' 1898.

constant and would not produce an error greater than one-twentieth of a degree C. Owing to slight changes in temperature from stroke to stroke during the working of the gas engine, the mean temperature at any part of the cycle could rarely be observed with an approximation closer than 1°. As the temperatures to be observed were about 100° C., no great refinements in testing the wire were required.

4. *The Periodic Contact-maker and the Electrical Connections.*—In order to observe the temperature at a definite point in the cycle, a periodic contact-maker was inserted, either in the galvanometer or in the battery circuit, and was set to close the circuit at the desired point. In this method errors may arise from thermo-electric or induction effects. Both effects were practically negligible with the apparatus employed, but the thermo-electric effects were rather larger and more variable than the induction effects. The periodic contact was, therefore, usually connected in the battery circuit, so as to eliminate the thermo-electric effects. The electrical connections, including the periodic contact-maker, are shown in fig. 5. In this diagram PS, QS are

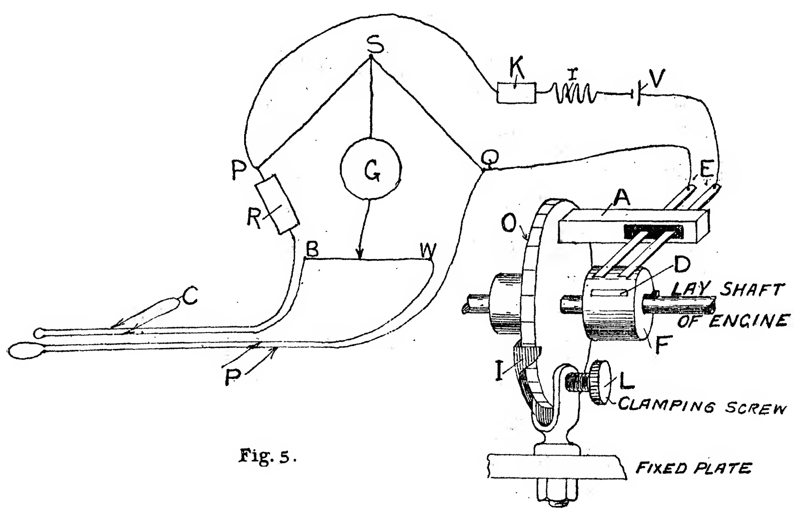

Fig. 5.

the equal ratio arms of the Wheatstone bridge. The galvanometer G is connected to the point S and to the sliding contact on the bridge wire BW. The thermometer and its leads P are connected on one side of the bridge wire, and the compensator C and the balancing resistance R on the other. The battery circuit includes a mercury reversing key K, an adjustable resistance r, and a storage cell V; and the battery is connected to the bridge at the points P and Q, and to the brushes of the periodic contact-maker at E. The brushes E are carried by an insulated arm A bolted to a divided disc O

riding loosely on the lay shaft of the engine, and capable of being clamped in any position by the screw L. The index I shows the crank angle, corresponding to the middle point of the contact when the insulated copper strip D carried in the fibre bush F passes under the brushes.

5. *Percussion Contact-maker.*—The common form of wipe-contact-maker illustrated in fig. 5 was employed in the earlier experiments, but was found to possess certain disadvantages. The contact was difficult to keep clean and the timing was liable to vary with speed and wear. The duration of contact could not be readily adjusted or accurately verified. In the later experiments a novel form of contact was adopted which appeared to be free from these defects. The construction of this contact-maker is illustrated in fig. 6. A brass bush B keyed to the lay shaft of the engine carries two fibre

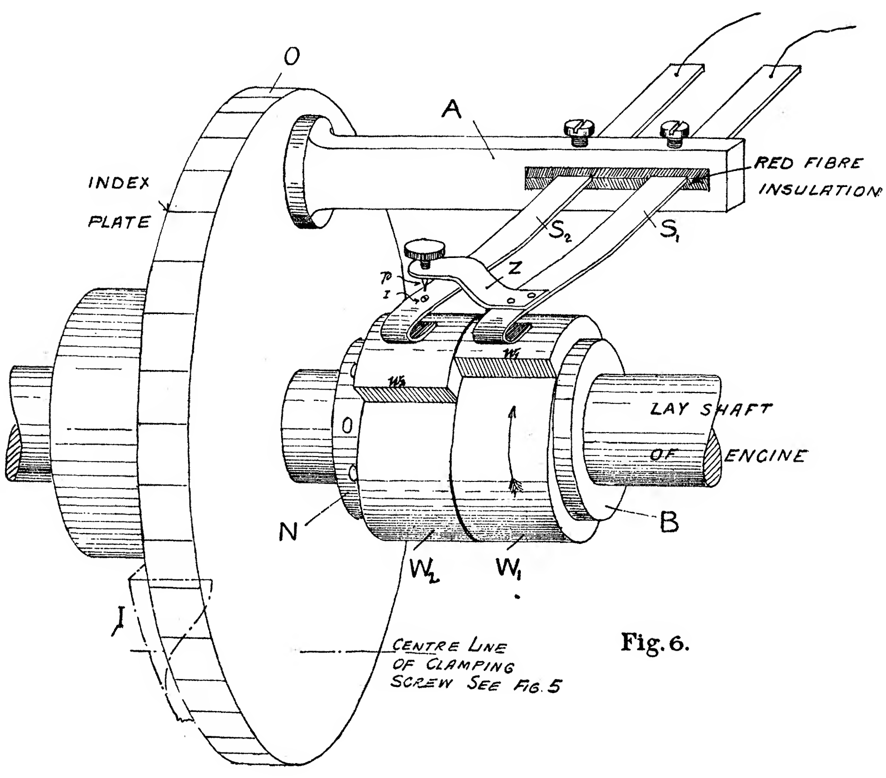

Fig. 6.

washers or cams W_1 and W_2 which can be clamped in any relative angular position against the flange of the bush by the nut N. A radial step, as w_1, is made in each washer and the surface gradually rises from the bottom of the step to the normal circular surface of the washer. The brushes of the wipe-contact are replaced by stiff springs S_1 and S_2, the reflexed ends of which

rest on the fibre cams. A projection Z carrying a platinum-pointed screw p is riveted to one of the springs and the screw p is adjusted so that its point is just clear of the platinum rivet r in the other spring when both springs are riding on the circular surfaces of their respective cams. Contact is made when the rotation of the lay shaft in the direction of the arrow brings the radial step w_1 of the cam W_1 under the spring S_1, thereby allowing it to fall down the step, thus bringing p and r together. Contact is broken when the radial step w_2 of the cam W_2 reaches the spring S_2, thereby allowing the second spring to fall down the step w_2. The epoch and duration of contact are readily adjusted by adjusting the angular positions of the cams relatively to the bush and also with regard to one another. The distance between the springs and the platinum contacts and the steps w are exaggerated in the diagram in order to make the principle of the apparatus clear. The percussion form of contact with platinum points was found to give more definite and certain results than the wipe pattern. It always kept itself clean, and no trouble of any kind was experienced with it. The duration of contact was generally adjusted to correspond with 20 degrees of the crank angle or 1/36 part of a revolution of the lay shaft.

6. *General Arrangement of the Engine.*—The only engine immediately available for the purposes of the tests was a 10 H.P. Crossley, forming part of the laboratory equipment of the Central Technical College, with a cylinder 7 inches bore and 14 inches stroke, the compression ratio being 4·68. It was not quite the latest pattern, but was in very good condition and well suited for testing the application of the method. It had porcelain tube ignition. It was directly connected to a four-pole dynamo of 8 kw. capacity, mounted on the same shaft. This arrangement was particularly advantageous, as it permitted the engine to be run under widely varying conditions of speed and load. For measuring temperatures by the periodic contact method, it is most important that the cycle of operations should be perfectly regular, and that there should be no missed explosions; otherwise it is impossible to take readings accurately, owing to the wide variations of temperature from stroke to stroke. With this object, the governor was disconnected, and the gas-admission valve arranged to open at every suction stroke. The field of the dynamo was separately excited, and the load taken by adjustable wire resistances, so that the engine could be made to run quite steadily at low speeds if desired. By a slight alteration in the electrical connections it was possible to supply the dynamo with current from the external lighting system, and employ it to drive the engine. This was required in some trials made for the purpose of testing the sensitiveness of the thermometers.

7. *Indicator Diagrams.*—When running the engine with rich mixtures, the

rapidity of the explosion was so great that satisfactory diagrams could not be obtained with the ordinary piston type of indicator. The sudden rise of pressure caused violent oscillations of the pencil, which continued throughout the stroke and made accurate readings impossible. For this reason, an optical indicator, or "manograph," of the Carpentier type was employed, with some modifications suggested by previous experience. In this instrument the pressure acts upon a steel disc or diaphragm, the movement of which is transmitted to a short optical lever, which carries a mirror reflecting a spot of light on to a photographic plate. The lever is pivoted on a fixed point and has a second arm at right angles to the first, which simultaneously receives a movement corresponding with the movement of the piston. This manograph was originally intended for taking diagrams from small high-speed motors with closed crank-chambers. It was supplied with a long, fine copper tube, for connecting the disc chamber to the cylinder, and with a long, flexible coupling to be attached to the crank-shaft, the rotation of which was made to reproduce the motion of the piston by means of a small crank actuating the arm of the optical lever. In adapting the manograph to the gas engine, we found it more convenient to dispense with these connections, which were a source of inaccuracy. The disc chamber was screwed directly on to the indicator cock of the engine. In the earlier experiments the piston motion was obtained from a sprocket wheel on the lay shaft, but later it was reproduced directly by means of a lever driven by a cord attached to the usual indicator rig connected to the piston of the gas engine. Fig. 7 shows the optical indicator in place, and also the sprocket wheel and band driving from the lay shaft. The figure shows incidentally also the general arrangement of the gear for working the admission and the thermometer valves, and the disc and contact-maker on the lay shaft, the details of which have already been illustrated diagrammatically in figs. 4 and 5.

As the pressure scale given by a plane disc is not one of equal parts, and is liable to vary slightly with slight differences in the clamping of the disc, the scale of the indicator was calibrated on each occasion in its actual position on the engine. A gas bottle and a standard pressure gauge were connected to the blow through hole of the indicator cock, and lines were traced on the photographic plate corresponding to equal intervals of pressure, and also lines at right angles to these corresponding to equal displacements of the piston. By using a grill prepared in this manner for measuring the diagrams, errors due to the variation of the pressure scale, or inaccuracy in the reproduction of the piston motion, are practically eliminated. By using discs of different thicknesses, or by different combinations of discs, a considerable range of pressure could be covered with

satisfactory accuracy. For the lower pressures, and for the tests in which the engine was driven by the electric motor without firing, a steam engine indicator of the Crosby pattern was also employed. This indicator was calibrated by weights placed upon a revolving plunger of known area, and

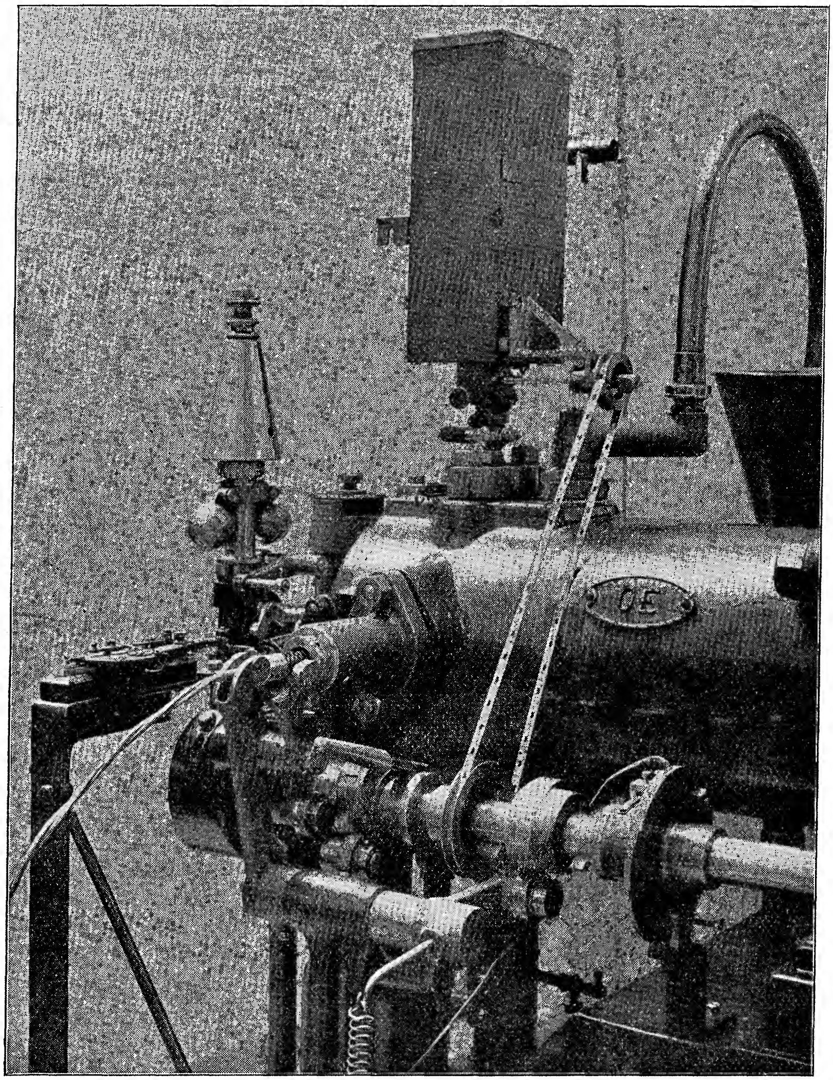

FIG. 7.

was found to be correct and to agree with the optical indicator in those tests in which diagrams were taken with both instruments.

8. *Testing the Platinum Thermometers for Lag.*—It was well known from previous experiments that a platinum wire, 0·001-inch diameter, was capable

of following the cyclical variation of temperature of a gas during suction and compression with sufficient accuracy for the determination of the suction temperature, but it appeared desirable to measure the lag of the thermometer at various speeds under these conditions, and to test whether a thermometer inserted in the manner already described could be relied upon to give the average temperature of the mixture in the cylinder, and how far its readings might be affected by the temperature of the valve in which it was enclosed. For this purpose the engine was driven by a motor, compressing and expanding a charge of air without firing. Temperature readings were taken throughout the cycle for comparison with the mean temperatures deduced from the indicator diagrams.

Two thermometers were employed which differed slightly in the disposition of the platinum loop. In the first, designated Pt_1, the fine loop was attached in the usual manner, projecting beyond the ends of the leads. In the second, designated Pt_2, the copper leads were made somewhat longer, and the platinum loop was inverted so as to lie between the leads. It was thought that with this latter method of construction the fine wire loop would be better protected from accidental damage in inserting or withdrawing the thermometer, and would be better able to withstand the shock of opening or closing the thermometer valve. This proved in fact to be the case. It was found, however, that the projecting loop Pt_1 suffered very little distortion, and that although the thermometers agreed very well on the readings of the suction temperature, the readings of Pt_2 were appreciably affected by the close proximity of the leads to the fine wire, when the difference of temperature between the leads and the surrounding gas was considerable.

Two kinds of motor-driven tests were made. In the first kind the gas-cock was shut and the valves were worked in the usual way, so that a fresh charge of air was taken in and compressed during each cycle. In the second kind the gas-cock was shut, the valve levers were removed, and the thermometer valve was fixed permanently open with the gas admission valve permanently closed, and the tension of the exhaust valve spring was relaxed so as to allow it to act as a non-return valve for admitting a little air to the cylinder to compensate for leakage at the end of each suction stroke. Under these conditions the piston expands and compresses a practically constant charge of air at each revolution, and there is little or no disturbance due to the opening and closing of valves. This made it possible to secure a more accurate comparison of the thermometer with the indicated temperatures throughout the cycle, and to obtain a more satisfactory estimate of the lag. With the valves opening and closing in the

ordinary way the cycle occupies two revolutions, and the readings of the thermometer from stroke to stroke are appreciably disturbed by slight variations in the opening and closing of the valves. Moreover, the mass of air contained in the cylinder is constant only for a part of each alternate revolution, so that the comparison with the indicator cannot be extended satisfactorily throughout the cycle.

9. *Comparison of the Temperatures recorded by the Thermometer with the Temperatures calculated from the Indicator Diagram.*—The comparison in the case of the first method of working, namely, valves opening and closing in the usual way, is made in fig. 8. The broken line represents the reading

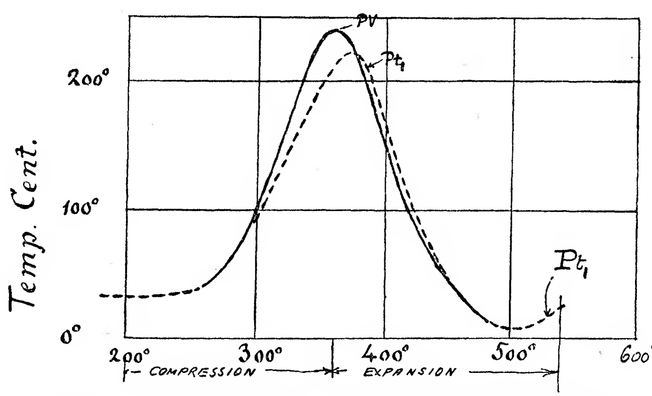

FIG. 8.—Crank Angle from beginning of Suction Stroke.

of the platinum thermometer Pt_1 in degrees Centigrade, plotted with reference to crank angle during the compression and expansion strokes. The full line represents the temperatures deduced from the corresponding indicator diagram by calculating the product PV for the period during which the mass of air enclosed remained sensibly constant. The average speed in this trial was 102 revolutions per minute. An appreciable leakage or loss of heat takes place during the period of maximum compression, so that the compression and expansion curves are not exactly superposed on the card, but each is sensibly adiabatic, following the law $PV^{1\cdot4} =$ a constant within the limits of error of the pressure measurements. It would make very little difference to the form of the curve between 260 degrees and 460 degrees of crank angle if the temperatures at each point were calculated from the pressures alone (instead of from the product PV), assuming the adiabatic law $\theta^{1\cdot4}/p^{0\cdot4} =$ a constant. The temperatures on the PV curve are calculated on the assumption that the mean temperature of the charge is given correctly by the platinum thermometer at 260 degrees of crank angle. It will be observed that the Pt curve is not quite

symmetrical with the PV curve, the lag appearing greater during compression than during expansion. This may have been caused by some peculiarity in the direction of the currents of air in the cylinder with reference to the position of the ribs of the thermometer valve during compression. The thermometer valve was fixed in this experiment with one of the ribs vertically over the other, so that the opening through the valve might be horizontal or parallel to the axis of the cylinder. During expansion, when the turbulent motion of the air due to admission had subsided, the motion is probably parallel to the axis of the cylinder and the lag of the thermometer is seen to be very small. The PV and Pt curves reunite towards the end of expansion. It was observed in another experiment that the effect of turning the thermometer valve through a right angle, so that the ribs should not obstruct the air current, was to raise the maximum indication 10° C. The reading at the lowest point corresponding with the suction temperature was not appreciably affected by the position of the thermometer valve. In a repetition of this test with the thermometer Pt_2 having the inverted loop, it was found that the close proximity of the copper leads to the fine wire raised the readings of the suction temperature 2° to 3° C. and lowered the reading of the maximum temperature nearly 20° C. It may be inferred from this test that a thermometer of the type Pt_1 with a projecting loop may be trusted to give the suction temperature with an approximation of 1° C., in spite of the presence of the enclosing valve, providing that the temperature of the valve does not differ greatly from that of the mixture in the cylinder. When the temperature is changing most rapidly and the temperature of the valve differs nearly 200° from that of the air, the thermometer lags only 20° and a change in the position of the ribs of the thermometer valve does not affect the readings by more than 10° C.

The comparison in the case of the second method of working, in which the valves are continuously closed, is illustrated in fig. 9. This method promised to afford a more accurate method of testing the thermometer owing to the greater steadiness of the conditions, which permitted more accurate readings of the temperature. Some unexpected difficulties were encountered owing to the presence of small quantities of water, resulting from the formation of fog, but the observations were in many respects instructive, and may be worth recording as additional evidence. The quantity of water required to saturate the clearance space at a temperature of 100° C. was only 0·003 of a pound. Nearly half of this quantity was found to have accumulated in some of the experiments, which afforded an interesting study in the adiabatics of fog. The effect of the formation of fog is very greatly to reduce the range of temperature for a given range of pressure, and the presence of water must,

therefore, be carefully avoided in this method of testing a platinum thermometer. In the test reproduced in fig. 9, the air in the cylinder was sufficiently dry for the calculation of the temperatures from the card by the PV method. The compression and the expansion curves were very nearly symmetrical and adiabatic. The motion of the air in the cylinder was parallel to the axis in both, and the PV and Pt curves were approximately symmetrical. The lag was greater than in fig. 8, partly owing to the higher speed (130 revolutions per minute), but partly also due to the more quiescent

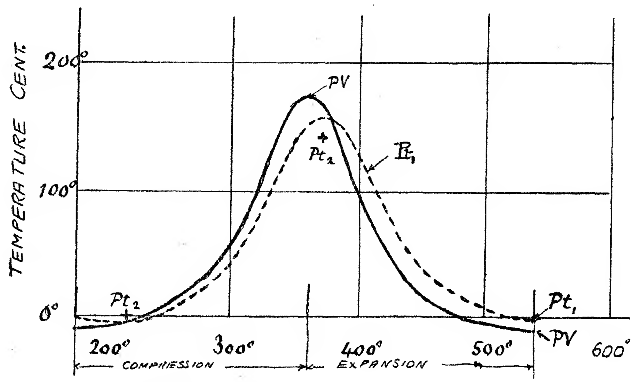

FIG. 9.—Crank Angle from beginning of Suction Stroke.

state of the air in the cylinder. The range of temperature with Pt_1 was from $-6°$ to $+159°$ C., as against $-10°$ to $+173°$ C., calculated from the card. It must be remembered, however, that there was probably a snow fog in the cylinder at $-10°$, which throws some doubt on the accuracy of the PV curve and would account for part of the lag of the thermometer owing to condensation on the wire. Also that an error of 1/1000 of an inch in measuring the card would make an error of 1° of temperature in the PV curve at this point. The range given by the inverted loop thermometer Pt_2 in this test was from 0° C. to 142° C., being reduced by the proximity of the wire leads, the temperature of which was approximately 50° C. The experiment was repeated with and without the thermometer valve in place. The presence of the valve lowered the reading of the platinum thermometer about 10° C. at the point of maximum temperature when the ribs were placed in the horizontal plane so as to obstruct the flow of the air through the aperture, but it did not make any appreciable difference when the aperture was horizontal.

10. *Suction Temperature in Gas Trials.*—A number of trials were run under various conditions of speed and load, and gas supply, with the engine driving the dynamo in the ordinary way. For these trials the thermometer

valve was adjusted to open about the middle of the suction stroke, and close soon after the middle of the compression stroke. The temperatures were observed at the end of the suction stroke, and just after the closing of the admission valve. An observation was also taken at the end of the compression stroke when the thermometer valve was closed in order to give the temperature of the valve itself. The suction temperature was found to vary with the conditions of running from about 95° C. on light load trials to about 125° C. at maximum load, the air temperature being in all cases nearly 20° C., and the jacket temperature 27° C. It should be remembered that in all these trials an explosion occurred at every second revolution, that is, there were no misses, the governor being entirely cut out. The trials were not, however, sufficiently extended to show the dependence of the suction temperature on the various conditions of load and speed and gas supply and jacket temperature. For the present the authors must content themselves with giving an illustration of the method of calculation they propose, reserving further discussion until more complete data are available.

The most interesting of the trials from a theoretical point of view are those with rich mixtures in which combustion is practically complete at constant volume and the diagram conforms most closely to the theoretical type. A typical example is shown in fig. 10, taken from trial 26, photo 62. Six consecutive explosions, photographed on the same plate, were practically identical. The following are the data of this trial:—

Revolutions per minute, 130;
Ratio of gas to air, 1 to 7·1;
Atmospheric temperature, 20° C.; jacket temperature, 27° C.;
Temperature of thermometer valve at 360 degrees crank angle, 122° C.;
Temperature of mixture in cylinder at 260 degrees crank angle, 111° C.;
Pressure in pounds per square inch absolute at 260 degrees crank angle, 18·5;
Volume of mixture at 260 degrees crank angle, 0·2846 cubic feet.

In calculating the temperatures along the expansion line, it is assumed that combustion is complete, and that the gases have undergone a molecular contraction, depending upon the richness of the mixture and the composition of the gas, which in this case amounts to 4·3 per cent. To find the temperature at any point in the expansion curve it is only necessary to divide the product of the pressure and volume at that point by the constant 0·01315, representing the observed value of the product pv/T at the point corresponding to 260 degrees crank angle λ, corrected for contraction. The resulting curve of temperature is shown in the upper part of the diagram (fig. 10). The temperature thus calculated is the apparent or effective

temperature, and includes the effect, if any, of dissociation. By comparing and analysing such curves it may be possible to deduce important relations bearing on the phenomena of combustion of gaseous mixtures. The curve shown in the diagram exhibits a marked change of curvature at 0·4 of the

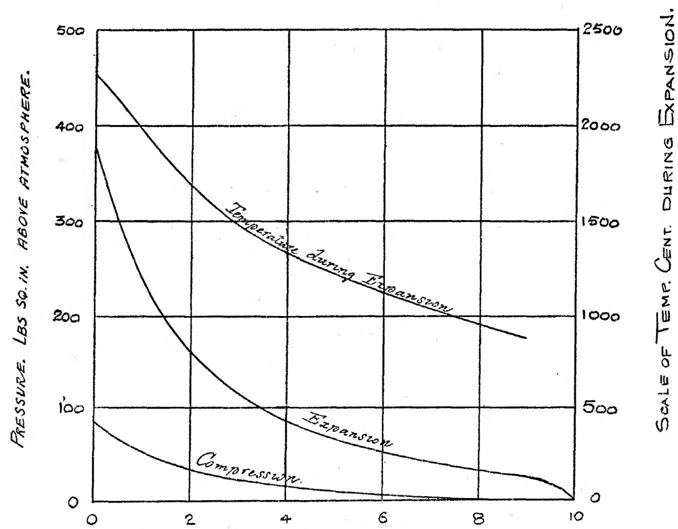

Fig. 10.—Trial 26. Diagram Photo 62.

stroke, and becomes nearly straight. A peculiarity of this kind might be due to some imperfection of the indicator, but it might also imply a further stage in the combustion. Without an exact knowledge of the suction temperature it would be impossible to investigate such points satisfactorily.

By a curious coincidence a diagram taken in another trial, fig. 11, trial 4,

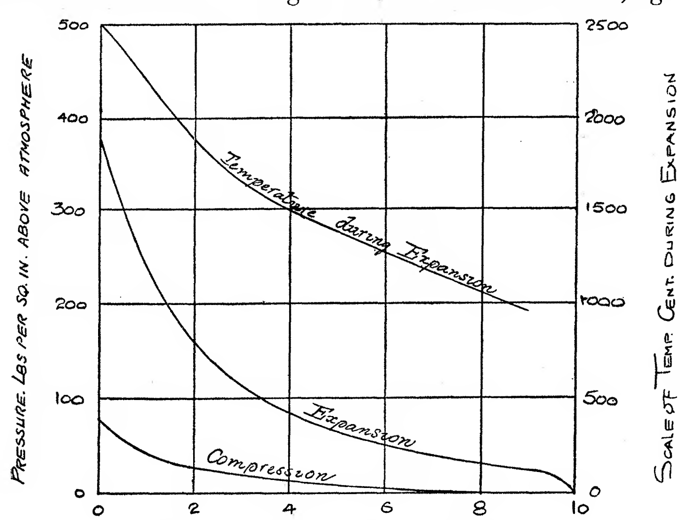

Fig. 11.—Trial 4. Diagram Photo 9.

photo 9, with a different ratio of gas to air, namely 1 to 5·8, gave a practically identical expansion curve, not differing by more than 1 pound at any point from the curve of the preceding example recorded on photo 62. The mean pressures deduced from the brake horse-power were also very nearly identical. Without a knowledge of the suction temperature it might be inferred that the two trials were really identical and that some mistake had been made in the gas measurements. The data for this trial are as follows:—

Revolutions per minute, 114. Ratio of gas to air, 1 to 5·8.
Atmospheric temperature, 21° C. Jacket temperature, 27° C.
Temperature of mixture at 260 degrees crank angle, 130° C., and pressure 17·8 lbs. per square inch absolute.
Molecular contraction on combustion, 5·1 per cent.

The constant for calculating the temperature along the expansion curve comes out 0·01195 in place of 0·01315, and the temperatures are all much higher, as they should be with a richer mixture. The temperature curve in fig. 11 shows the same curious anomaly as that from photo 62 in fig. 10, although the diagram was taken with a different disc having a different pressure scale, and with an entirely different arrangement of indicator gear, the piston motion being transmitted from the lay shaft in the way shown in fig. 7, instead of being taken direct from the usual indicator rig as was the case in Experiment 26.

11. *Conclusions.*—It appears probable from these experiments that the temperature of the thermometer valve never differs very much from the temperature of the gases shortly after the closing of the admission valve in the method of construction adopted by the authors, in which the thermometer valve is inserted through the spindle of the admission valve. In a specially designed gas engine, a separate opening might be provided for the insertion of the thermometer, but it is probable that the temperature of the valve in this case would not be so nearly equal to the suction temperature to be measured. The method adopted by the authors has the advantage that it can be applied without difficulty to any existing engine by simply making a special admission valve. Since the temperature of the thermometer valve in this method of construction differs so little from the suction temperature at the required point, it appears probable that the thermometer gives the actual suction temperature required with an approximation of the order of 1° C. The temperature at this point can probably be measured with a fine wire with a greater degree of accuracy than the pressure. In order to obtain the pressure at this point, it is necessary to take a diagram

with a light spring in the indicator, as the pressure cannot be satisfactorily measured with a spring strong enough to record the explosion temperature. Further, it is absolutely necessary in these investigations that the engine should repeat a perfectly regular cycle at each explosion. No results of any value can be obtained with a hit-and-miss governor in operation, because the conditions vary too greatly from stroke to stroke. This has been repeatedly shown by previous trials. In measuring the expansion and exhaust temperatures by a similar method, it would be most appropriate so far as the temperatures to be measured are concerned to insert the thermometer valve through the spindle of the exhaust valve.

The authors desire to record their obligation to Mr. Witchell and Mr. Betterley and to other members of the Laboratory staff for the able assistance they severally gave during the investigation.

Fig. 2.

Fig. 3.

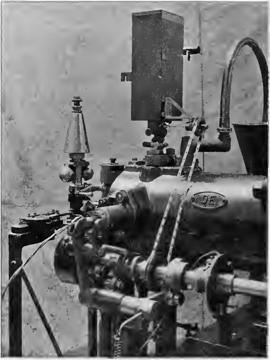

FIG. 7.